

Multitone Phase-Cal Mode in *fourfit*

Roger Cappallo
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Introduction

In the past, there were three different phase calibration modes that were employed in *fourfit*, with each having its own strengths and applicable usage cases. A brief summary of their characteristics is given in Table 1. This memo describes a new mode, called multitone mode, which introduces new capabilities, as well as incorporating most of the functionality of the 3 previous modes.

mode	description	advantages	disadvantages
normal	any single tone extracted by corr. hardware	simplicity	poor snr due to ignored tones
manual	each channel's phase is manually specified	can be determined by peaking on a strong calibrator and used for a whole experiment; no thermal noise added	labor-intensive; requires calibrator scan; doesn't follow scan to scan variation
ap_by_ap	pcal phase for a single tone is extracted and applied independently for each AP	able to track a "wandering" phase	introduces extra noise into fringe phase; poorest snr

Table 1 Prior phase cal modes in *fourfit*

Multitone Features

- **multiple tones within each channel**¹ – the coherent sum of all tones within the channel's bandpass is formed, a best-fit delay determined, the phase is evaluated at mid-band, and applied
- **masking of tones by channel** – in order to avoid contamination of the phase calibration by strong interfering tones, it is possible to select for use any subset of the tones within the band, by way of a excluded tone mask
- **flexible averaging over time** – since phase corrections can vary over time within a scan, perhaps not even in a linear fashion, the multitone phasecal correction can be segmented over time. The integration period is user-adjustable so that the phase can be tracked with a minimum effect on the noise added into the interferometric fringes by pcal phase noise.
- **additive phases by channel** – for flexibility it is sometimes useful to apply an extra additive phase, on a channel by channel basis

¹ a Mk4 channel, which is called a subband by the difx community, consists of a single chunk of frequency space represented by a single sample stream, and used to be the SSB output of either a Mk4 video-converter or a VLBA baseband converter.

Mathematical Underpinnings

Let us define:

N	# of tones within the band
f_n	frequency of the n^{th} phase cal tone within the band (Hz)
f_c	center frequency of the band (Hz)
ρ_n	complex phasor of the n^{th} tone, as measured
τ_n	best-fit delay (s) to tones across the band
P_n	coherent sum at mid-band

To find the best-fit delay we take the complex phasors for all of the included tones within the band, which – due to their means of generation by a short pulse - all fall nicely on a grid of equally spaced points in frequency, and find the peak (delay) of their FFT. In order to increase accuracy, the phasors are first 0-padded, which is equivalent to using a sinc interpolator on the delay function. Using the best-fit delay, we then counter-rotate the individual phasors to the center frequency (since we are correcting the *mean* channel phase) and form their sum:

$$P_n = \sum_{n=0}^{N-1} \rho_n e^{-i2\pi(f_n - f_c)\tau_n}$$

The phase of this complex result, $\arg(P_n)$, is used to correct the fringe phase of the channel.

Syntax and Usage

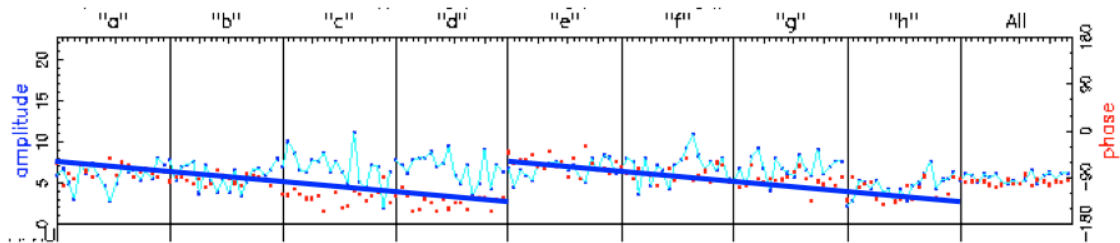
A fourfit user invokes and controls multitone mode by adding one or more lines to the fourfit control file. The stations to which a particular specification is applied are determined by the normal fourfit control file context rules. The applicable stations could be established, for example, by a construct of the form `if <station>` or `if <baseline>`, or the scope could be global (specified prior to any ifs). The relevant commands, all of which are optional, are

- **pc_mode multitone** – command to specify multitone mode
- **pc_period <period>** – an integer specifying the averaging period in AP's (default is 9999, i.e. the whole scan)
- **pc_tonemask <chan_specifier> <mask1> <mask2> ...** – an integer tone exclusion mask is given for each of the specified channels; each bit within an exclusion mask corresponds to a tone within the channel; if set, bit 0 omits the 1st tone from the fit, bit 1 omits the 2nd tone, and so on. This is useful for leaving out RFI-corrupted tones from the fit across the channel.

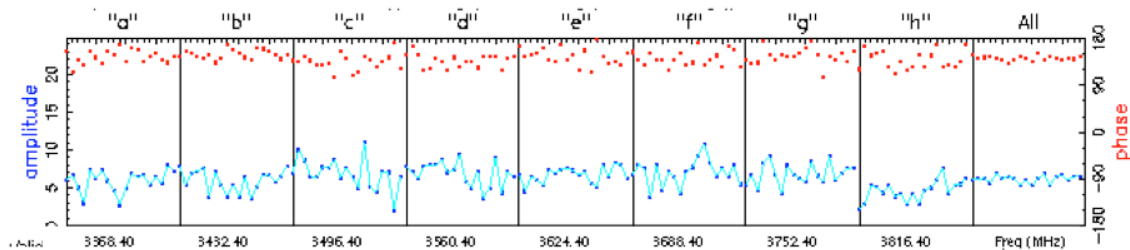
- `pc_phases <chan_specifier> <ch1_phase> <ch2_phase> ...` – specifies, for each named channel, an additional phase to be added to the values normally extracted by multitone mode.

Examples

Example 1: comparison of normal and multitone phase cal modes when the tone sequence occurs at different points within different bands. When using normal mode the correction phase depends on the placement of the tone that is being extracted, due to the delay from injection point to where the waveform is sampled.



phases adjusted by first tone within band (3.4, 2.4, 1.4, 0.4, 4.4, 3.4, 2.4, 1.4 MHz)



phases adjusted using multitone mode (Westford-GGAO baseline)

Example 2: The effect of using a shorter (than the whole scan) pcal integration period when the phase cal has a jump in phase (shown in red). In this case, setting pc_period to 3 AP's allowed the program to track the phase cal jump (not shown here) in channel "c", resulting in the relatively continuous phase of the bottom panel.

